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EPSRC Centre for Doctoral Training in Metamaterials XM[2]

Atomically Thin Cameras

"Fast and Highly Sensitive Ionic-Polymer-Gated WS_2–Graphene Photodetectors"

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What is this poster about?

Photodetectors have to be both sensitive to, and quick to respond to, small changes in illumination.

We have demonstrated for the first time an atomically thin photodetector that can detect light under half-moon illumination levels, whilst operating at video-frame-rate imaging speeds.

Why is our work important?

Unlike other atomically thin photodetectors, the high photo-sensitivity of our devices is achieved without compromising on operational speed. Our findings could enable the creation of atomically thin video cameras capable of night-time operation.

1. Fabrication

Few-layer WS_2, tungsten disulphide, was mechanically exfoliated from natural crystals and transferred onto the SiO_2 substrate by means of adhesive tape.

High-quality graphene grown by chemical vapour deposition was then transferred onto the WS_2.

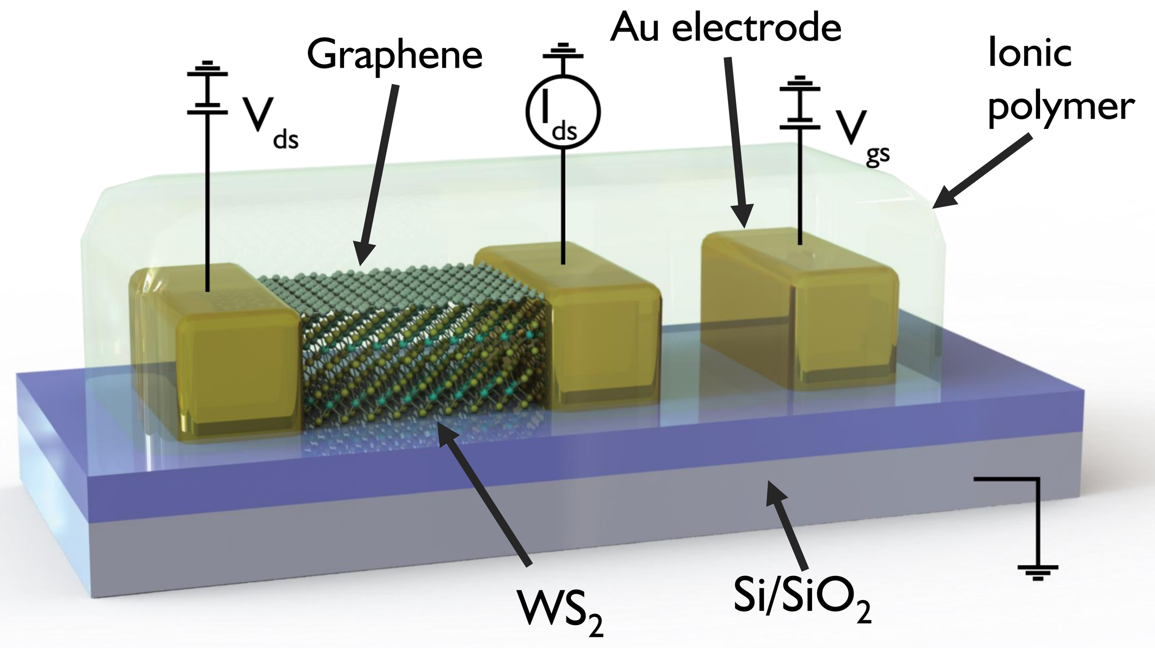

Fig. 1. 3D illustration of WS_2-graphene photodetector with electrical connections included.

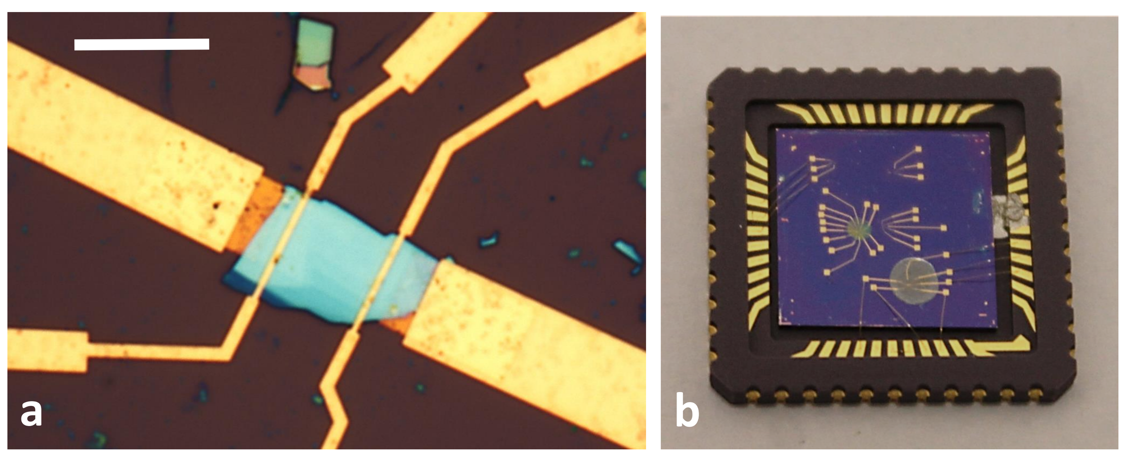

Fig. 2. (a) Optical micrograph of WS_2-graphene photodetector. Scale bar is 10 µm. (b) Device packaged and bonded for measurements in a 1.5 cm x 1.5 cm chip carrier.

Graphene channels were defined through O_2 plasma etching.

Electrical contacts were defined by electron-beam lithography and deposition of Au (20 nm).

A transparent ionic polymer ($LiClO_4$/PEO) was deposited, which serves as a top gate.

2. Method

The photodetector performance and spectral response measurements were performed in a custom-built vacuum chamber (10^{-3} mbar).

The sample was illuminated by a spectrally tuneable incident light source.

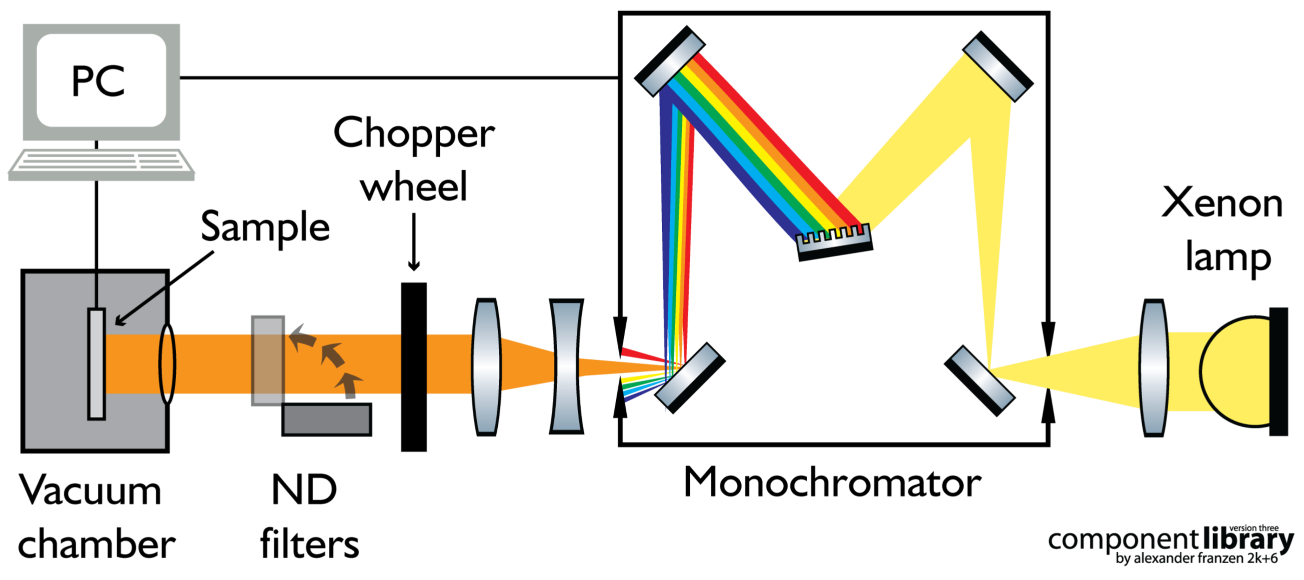

Fig. 3. Schematic of experimental set-up for photodetector characterisation.

Neutral density (ND) filters and a motorized chopper wheel were used to attenuate and modulate the incident signal, respectively.

3. Key Parameters

Parameter	Equation	Definition
Responsivity	$R = \frac{I_{pc}}{P}$ [A/W]	Ratio of the photocurrent, I_{pc}, to the optical power, P, incident on the device.
Rise (fall) time	τ_r (τ_f) [s]	The rise and fall time are defined as the time period taken for ΔI_{pc} to change from 10% (90%) to 90% (10%) of its maximum value, respectively.
Bandwidth	$f_{-3dB} \sim \frac{0.35}{\tau_r}$ [Hz]	Frequency at which the photocurrent drops to $\sqrt{1/2}$ of its DC value.

4. Optoelectronic Characterisation

Modulating the voltage applied to the ionic polymer (V_{gs}) controls both the charge carrier density in the graphene channel and the charge transfer at the WS_2/graphene interface. Applying a non-zero source-drain bias (V_{ds}) ensures the entire structure is photoactive.

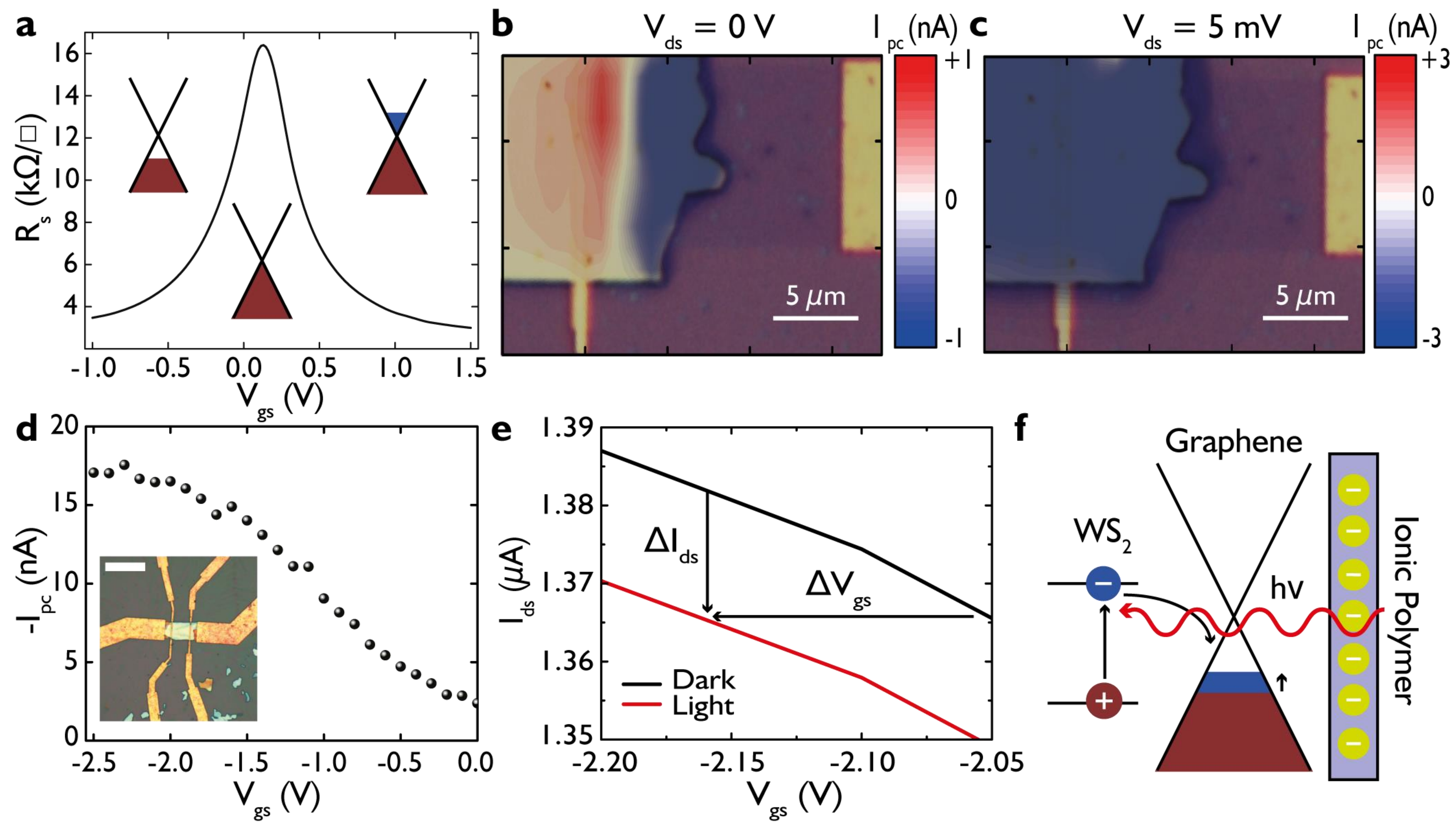

Fig. 4. (a) Channel resistance (R_s) as a function of gate voltage (V_{gs}). (b,c) Scanning photocurrent maps of a large-area device. d) Photocurrent (I_{pc}) versus top gate voltage (V_{gs}). Inset scale bar is 16 µm. e) Drain current (I_{ds}) versus V_{gs} in dark and under illumination. f) Schematic of charge transfer at WS_2/graphene interface.

5. Spectral Response

These devices display an energy dependent responsivity, R, when illuminated by monochromatic light. A photoresponse is observed across a broad spectral range but only for incident photons of energy greater than 1.8 eV, corresponding to the absorption edge of WS_2.

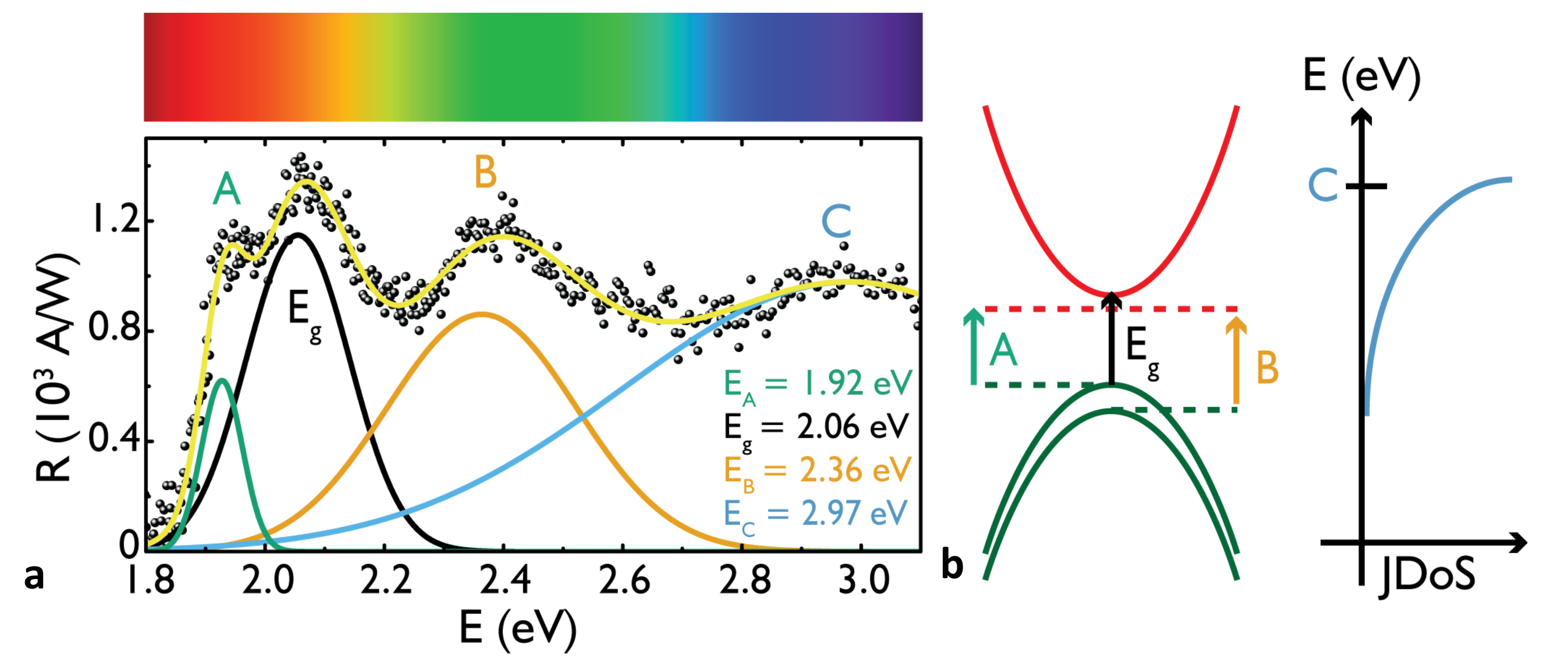

Fig. 5. (a) Responsivity (R) versus photon energy (E). (b) Schematic of electronic transitions in WS_2.

6. Photodetector Performance

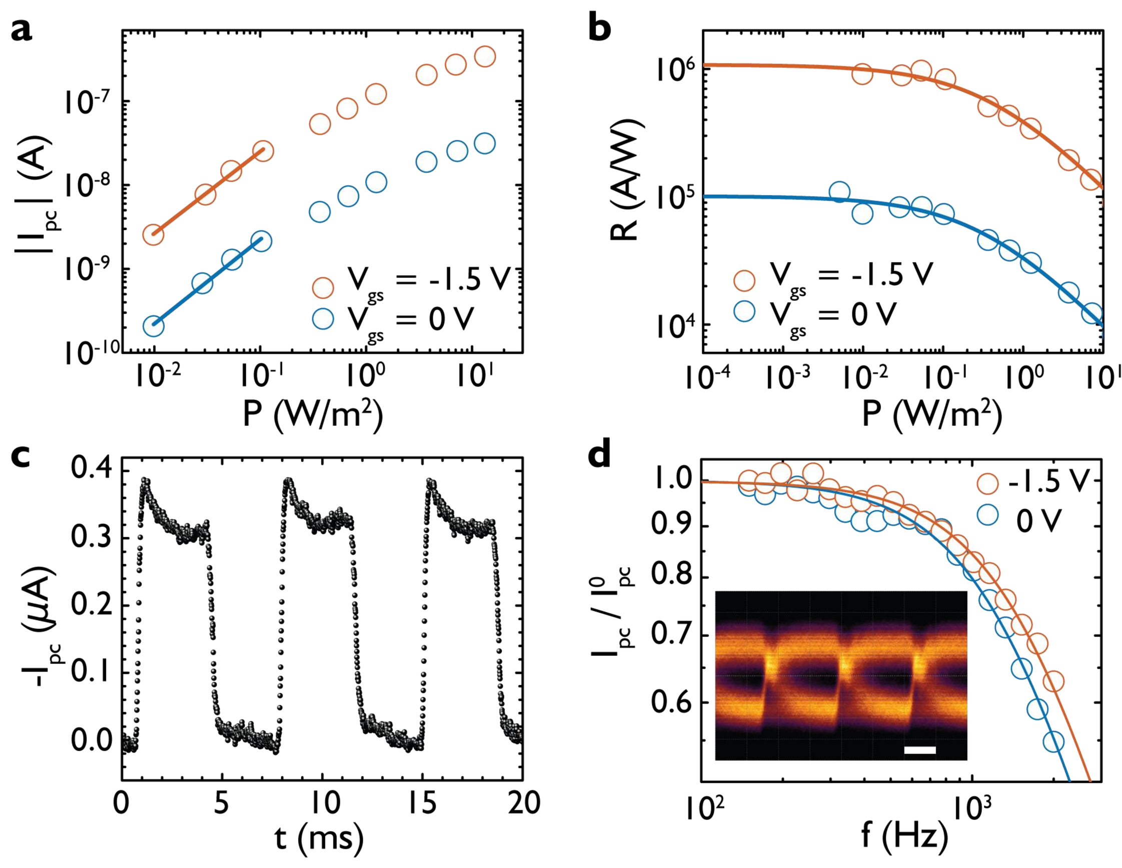

Fig. 6. (a) Photocurrent (I_{pc}) and (b) responsivity (R) as a function of incident optical power (P). (c) Temporal response of I_{pc}. (d) Normalised I_{pc} versus modulation frequency. Inset eye diagram scale bar is 150 µs.

Highly sensitive to light
High gain process in graphene channel arising from photogating effect leads to high sensitivity.

Video-rate response speeds
Fast response times arise from the ability to compensate charge traps with the ionic polymer, which is a limiting factor in similar photodetectors.

Proof of concept
Eye diagram with open eye at 2.9 kbit s^{-1} verifies that these heterostructures can truly be used in video-frame-rate imaging applications.

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